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AEROTHERMODYNAMIC EVALUATION OF CANDIDATE MATERIALS FOR SRAAM-T--ETC(U)
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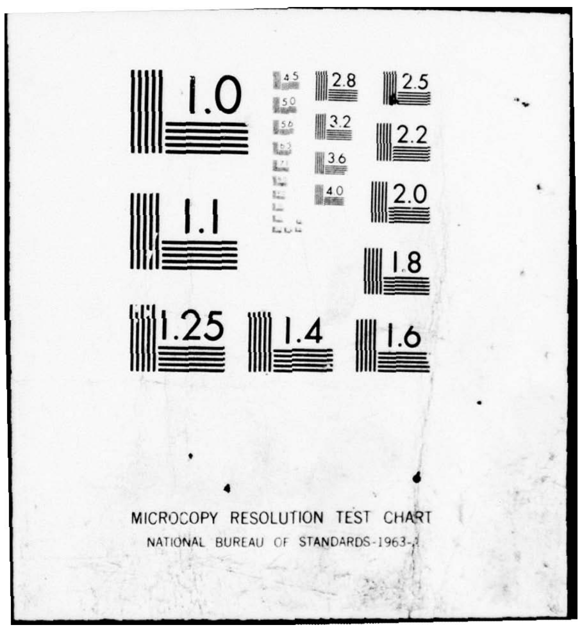
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AEDC-TSR-78-V42
NOVEMBER 1978

LEVEL II

AEROTHERMODYNAMIC EVALUATION OF CANDIDATE MATERIALS FOR SRAAM-TYPE MISSILE SYSTEMS

J. O. Ievalts
ARO, Inc., AEDC Division
A Sverdrup Corporation Company
von Kármán Gas Dynamics Facility
Arnold Air Force Station, Tennessee

Period Covered: October 11, 1978

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FOR THE COMMANDER :

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Ohio 45433

ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

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S-glass
graphite fibers

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
A materials screening test was conducted in the von Karman Gas Dynamics Facility Hypersonic Wind Tunnel C to determine the performance of several materials considered for potential use as missile control surfaces and fuselage body panels. The material samples were tested using the wedge technique. Test conditions were representative of the aerothermal environment encountered during a typical missile flight profile. Twenty-seven material specimens were tested with photographic coverage being the primary data. Selected results are presented to illustrate the test techniques and to show typical data obtained.

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II. TABLES

NOMENCLATURE

ALPHA-SECTOR	Tunnel sector angle, deg
C_2	Gardon gage calibration factor, $\frac{BTU/FT^2\text{-SEC}}{mv}$
DELT	Gardon gage temperature difference, °R
EXPOSURE TIME	Total time samples exposed to flow, sec
HO	Total enthalpy based on TO, Btu/lbm
H(TO)	Heat-transfer coefficient based on TO, $\frac{\text{Q-DOT}}{\text{TO-TW}}$, Btu/ft^2-sec-°R
M_∞	Free-stream Mach number
MU-INF	Free-stream viscosity, lbf-sec/ft^2
P-INF	Free-stream pressure, psia
PO	Tunnel stilling chamber pressure, psia
Q-DOT	Measured heat-transfer rate, Btu/ft^2-sec
Q-INF	Free-stream dynamic pressure, psia
RE/FT	Free-stream Reynolds number, ft^{-1}
RHO-INF	Free-stream density, lbm/ft^3
ROLL-SECTOR	Tunnel roll angle, deg
S	Surface distance in axial direction from wedge leading edge, in. (see Fig. 2)
TC1 thru TC11	Material sample thermocouple temperature, °F
TGE	Gardon gage edge temperature, °R
TIME	Time from entering the tunnel flow, sec
T-INF	Free-stream temperature, °R
TO	Tunnel stilling chamber temperature, °R
TW	Gardon gage temperature, °R
V-INF	Free-stream velocity, ft/sec
WEDGE-ANGLE	Angle between free-stream velocity vector and wedge surface, deg

X	Axial distance from wedge leading edge, in.
Y	Vertical distance from wedge surface, in.
Z	Lateral distance from model centerline, in.

1.0 INTRODUCTION

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 62102F, Control Number 2417-008, at the request of the Air Force Materials Laboratory (AFML/MXE), Wright-Patterson Air Force Base, Ohio. The AFML/MXE project monitor was Mr. John Rhodehamel. The results were obtained by ARO, Inc., AEDC Division (a Sverdrup Corporation Company), operating contractor for the AEDC, AFSC, Arnold Air Force Station, Tennessee. The test was conducted in the von Karman Gas Dynamics Facility (VKF), Tunnel C on October 11, 1978, under ARO Project Number V41C-W3.

A materials screening test was conducted on candidate material specimens which are being considered for use on the next generation of air-to-air missile systems (SRAAM)+. The objective of the test was to expose a series of composite material samples to a simulated aerothermal environment representative of that encountered during a typical missile flight. To provide this environment, the VKF materials testing wedge was used to support the test specimens. The oblique shock wave generated by the wedge was used to reduce the local Mach number on the wedge surface to the desired supersonic level. The tunnel stagnation conditions were adjusted to produce the desired local pressure and temperature levels. Additional information on this technique can be found in Ref. 1. All runs were made at a wedge angle of 21 deg with nominal tunnel stilling chamber conditions of 1220 psia and 2185 °R. Boundary-layer trips were installed on the wedge to promote turbulent flow.

Inquiries regarding the test specimens and test data should be directed to AFML/MXE, Wright-Patterson Air Force Base, Ohio 45433. A microfilm record has been retained in the VKF at AEDC.

2.0 APPARATUS

2.1 TEST FACILITY

Tunnel C (Fig. 1) is a closed-circuit, hypersonic wind tunnel with a Mach number 10 axisymmetric contoured nozzle and a 50-in.-diam test section. The tunnel can be operated continuously over a range of pressure levels from 200 to 2000 psia with air supplied by the VKF main compressor plant. Stagnation temperatures sufficient to avoid air liquefaction in the test section (up to 2260°R) are obtained through the use of a natural gas fired combustion heater in series with an electric resistance heater. The entire tunnel (throat, nozzle, test section, and diffuser) is cooled by integral, external water jackets. The tunnel is equipped with a model injection system, which allows removal of the model from the test section while the tunnel remains in operation. A description of the tunnel may be found in Ref. 2.

+Short Range Air-to-Air Missile.

2.2 TEST HARDWARE

The materials testing wedge (Fig. 2), provided by VKF, was used to support the test specimens. The wedge is basically a 15-in. x 41.5-in. long flat plate mounted to a 13-deg wedge block. The flat plate has a back-step occurring 17.5-in. aft of the leading edge. The basic wedge angle is 13 deg; however, offset sting adapters were used in conjunction with the tunnel pitch mechanism to provide a wedge angle range from 0 to 28 deg.

The test specimens consisted of 39 individual material samples configured to represent missile control surface leading edges and 12 flat panels which represented the missile fuselage surface structure. The 39 leading-edge samples were bonded with RTV® to 15 square steel rods (0.625 in. x 15.75 in.) so as to provide a means of support during the test. Each material sample was instrumented with CR-AL® thermocouples in order to obtain a material backside temperature history during each exposure. All of the material samples were supplied by the AFML. A listing of the samples with their respective sample codes is presented in Table 1.

In addition to the material specimens, a steel "calibration plate" instrumented with heat-rate Gardon gages was installed during the runs involving the leading edges. The "calibration plate" as well as the flat panels were supported by phenolic spacers to insure that the top surfaces of the samples or "calibration plate" were level with the forward portion of the wedge. A sketch of the techniques used to support the flat panels and the leading edges is shown in Fig. 3. A sketch of the test assembly installed in the Tunnel C test section is shown in Fig. 4.

2.3 TEST INSTRUMENTATION

2.3.1 Test Conditions

Tunnel C stilling chamber pressure is measured with a 500- or 2500-psid transducer referenced to a near vacuum. Based on periodic comparisons with secondary standards, the accuracy (a bandwidth which includes 95 percent of the residuals; i.e., 2σ deviation) of the transducers is estimated to be within ±0.1 percent of reading or ±0.25 psi, whichever is greater, for the 500-psid range and ±0.1 percent of reading or ±1.25 psi, whichever is greater, for the 2500-psid range. Stilling chamber temperature measurements are made with CR-AL thermocouples which have an uncertainty of ±(1.5°F + 0.375 percent of reading) based on repeat calibrations (2σ deviation).

2.3.2 Test Data

The primary data consisted of 70 mm sequenced color photographs taken with a camera installed to view the flat panels from the top of the tunnel and the leading-edge samples thru the upstream side window. The cameras were started at the beginning of each inject and operated at a nominal rate of one frame every second. In addition to the primary data, backup data were obtained with 16 mm motion cameras mounted adjacent to the sequenced cameras. The motion picture cameras were operated at 20 frames per second.

Measurement of the material "front face" and "backside" temperatures were attempted with CR-AL thermocouples. The location of these thermocouples on the samples is shown in Fig. 5. Considerable difficulty was experienced in attaching these thermocouples, particularly with regard to their depthwise location. A thermocouple "bead" was formed and RTV was used as the bonding agent; however, in many cases, it appeared that the actual thermocouple junction was not on the material surface. This can produce temperature measurements which are significantly low; therefore the higher measurements are the most meaningful. The output of the thermocouples was recorded on a Beckman 210 analog-to-digital conversion system with each output scanned every 0.5 sec. Also, wedge surface heating rates were measured with Gardon gages located as shown in Fig. 2. During each injection, two flow-field shadowgraph photographs were obtained. The photographs were obtained by a single-pass optical flow visualization system with a 17-in. diameter field of view.

3.0 TEST DESCRIPTION

3.1 TEST CONDITIONS AND PROCEDURES

3.1.1 General

A summary of the nominal tunnel conditions are given below.

M_∞	PO, psia	TO, °R	Q-INF,psia	P-INF,psia	RE/FT x 10^{-6}
10.14	1220	2185	1.8	0.03	1.1

A test summary showing all configurations tested and the variables for each is presented in Table 2.

In the VKF continuous flow wind tunnels (A, B, C), the model is mounted on a sting support mechanism in an installation tank directly underneath the tunnel test section. The tank is separated from the tunnel by a pair of fairing doors and a safety door. When closed, the fairing doors, except for a slot for the pitch sector, cover the opening to the tank and the safety door seals the tunnel from the tank areas. After the model is prepared for a data run, the personnel access door to the installation tank is closed, the tank is vented to the tunnel flow, the safety and fairing doors are opened, and the model is injected into the airstream. After the data is completed, the model is retracted into the tank and the sequence is reversed with the tank being vented to atmosphere to allow access to the model in preparation for the next run. The sequence is repeated for each configuration change.

3.2 DATA REDUCTION

The primary data for this test were the photographs. In addition, wedge surface heating rates were obtained by the use of Gardon heat-rate gages (see Fig. 2). The heating rates as measured by the gages were computed by the equation

$$\text{Q-DOT} = (C_2)(\Delta E)$$

where ΔE ~ gage millivolt output

C_2 ~ gage calibration factor.

The calibration factor for each gage was obtained by direct measurement of the gage output for a known heating-rate input. These calibrations were performed by personnel of the VKF Instrumentation Branch.

The conversion from heating rate to heat-transfer coefficient was accomplished by the relation

$$H(TO) \equiv \frac{Q\text{-}DOT}{TO-TW}$$

where

TO ~ measured tunnel stagnation temperature, °R

TW ~ effective wall temperature of the gage, °R

3.3 UNCERTAINTY OF MEASUREMENTS

3.3.1 Test Conditions

Uncertainties in the basic tunnel parameters were estimated from repeat calibrations of the PO and TO instruments and from the repeatability and uniformity of the tunnel flow during calibrations.

Mach No.	Mach No. Nonuniformity	Uncertainty (±), percent PO	Uncertainty (±), percent TO
10.14	±0.08	0.1	0.4

3.3.2 Test Data

No precision can be quoted on the photographic data (primary data) but several pretest exposures of the test hardware in the tunnel were made to determine the correct camera settings for the available lighting conditions.

The precision of the heat-gage measurements is estimated to be ±5 percent. The wall temperature measurements associated with each heat gage have an uncertainty of ±0.5 percent of reading based on the wire manufacturer's specifications. Combination of these uncertainties results in an overall uncertainty in the heat-transfer coefficient of ±6 percent.

4.0 DATA PACKAGE PRESENTATION

Examples of the pretest and posttest photographs for the leading edge configuration are presented in Fig. 6 and for the flat panel configuration in Fig. 7.

A typical plot of the temperature-time history for one leading edge specimen is shown in Fig. 8. Gardon gage data from several groups are presented in Fig. 9 to demonstrate the group to group repeatability of the data. Sample tabulated data for each data type are presented in Fig. 10.

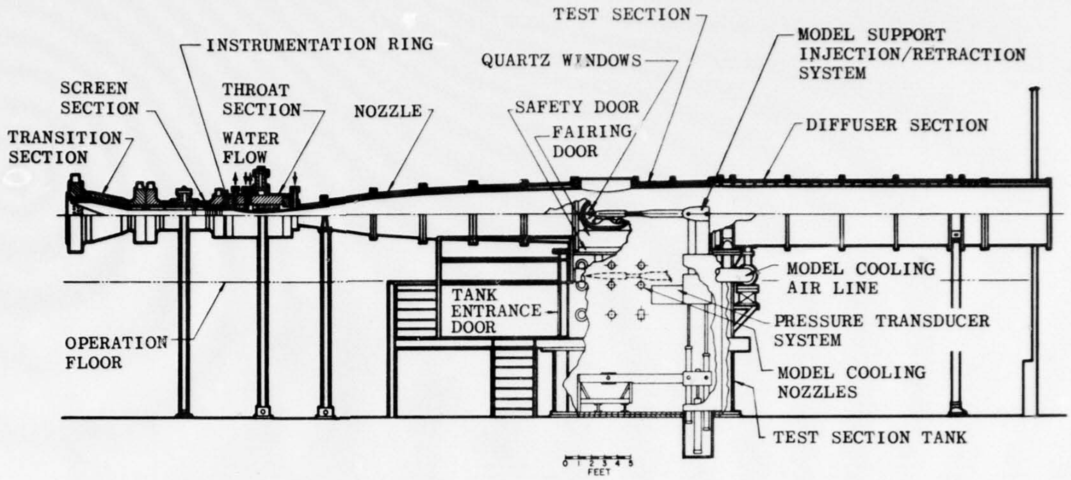
REFERENCES

1. Matthews, R. K. and Stallings, D. W. "Materials Testing in the VKF Continuous Flow Wind Tunnels," Presented at AIAA 9th Aerodynamic Testing Conference, Arlington, Texas, June 1976.

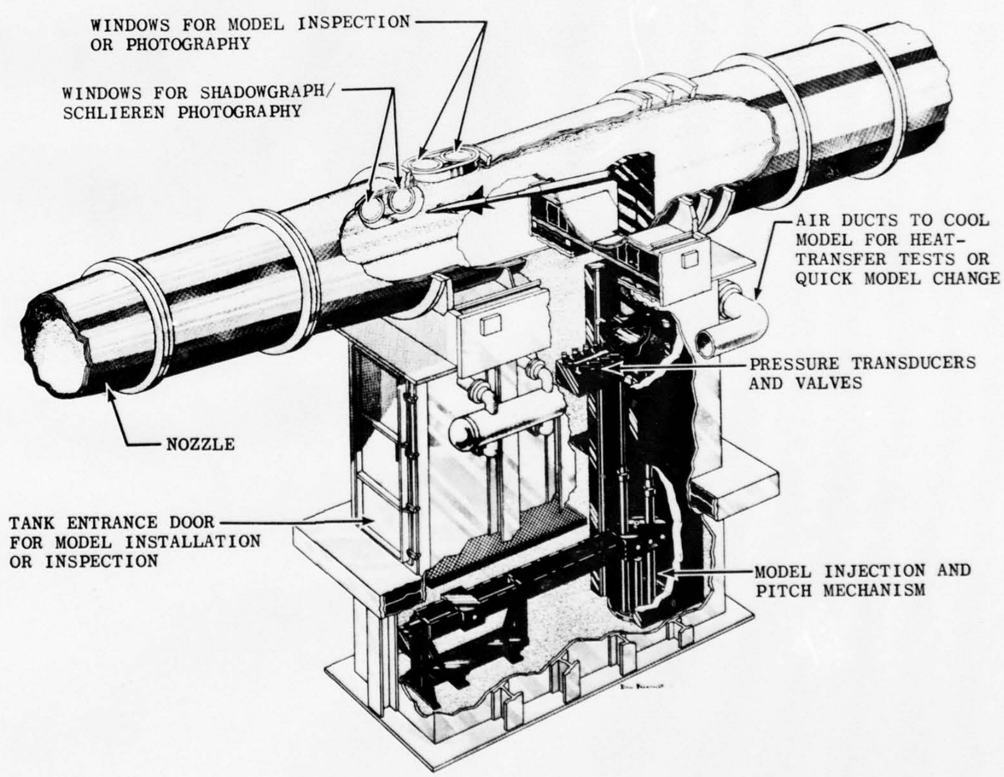
2. Test Facilities Handbook (Tenth Edition) "von Karman Gas Dynamics Facility, Vol. 3," Arnold Engineering Development Center, May 1974.

APPENDIX I

ILLUSTRATIONS



a. Tunnel assembly



b. Tunnel test section
Fig. 1 Tunnel C

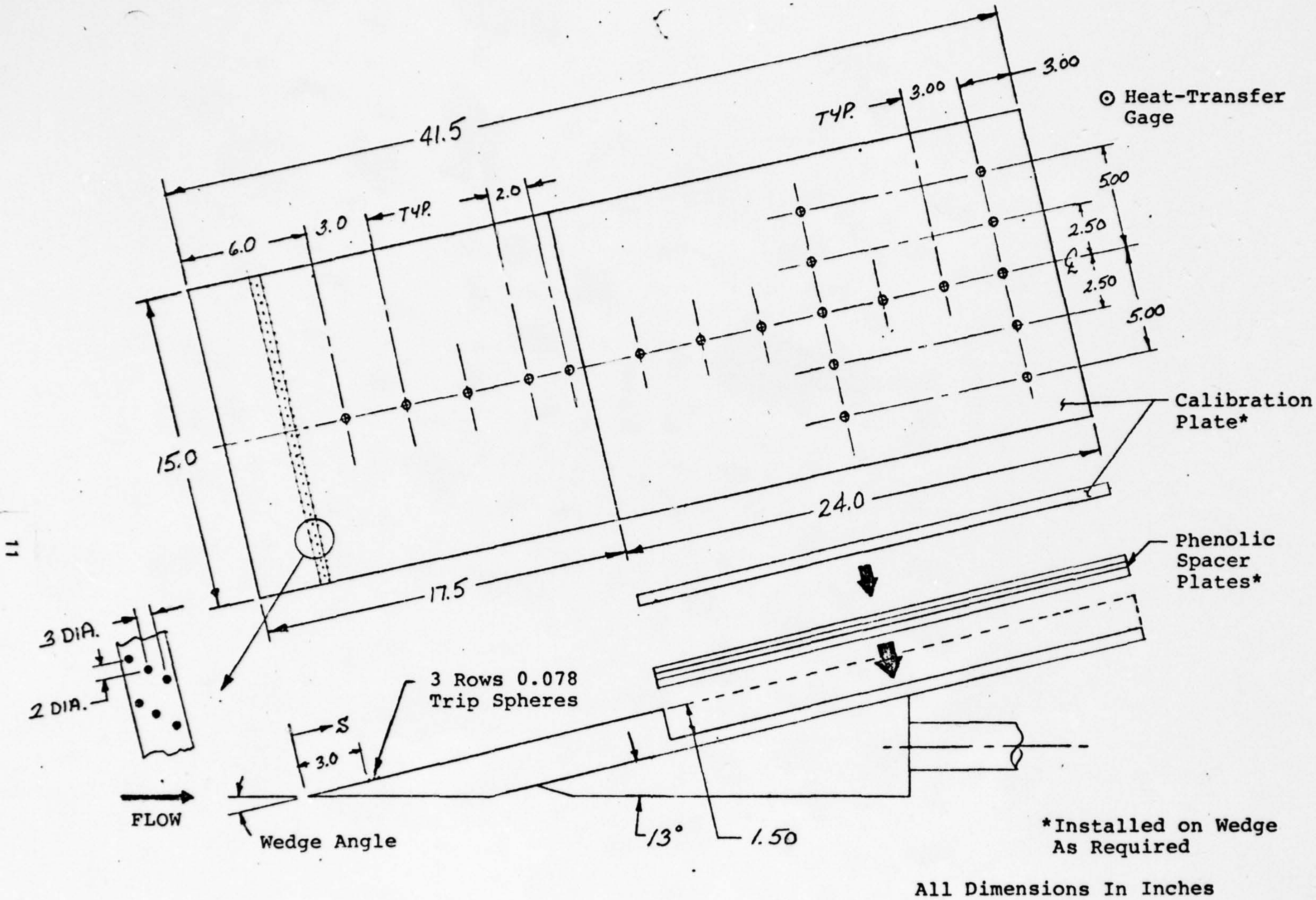
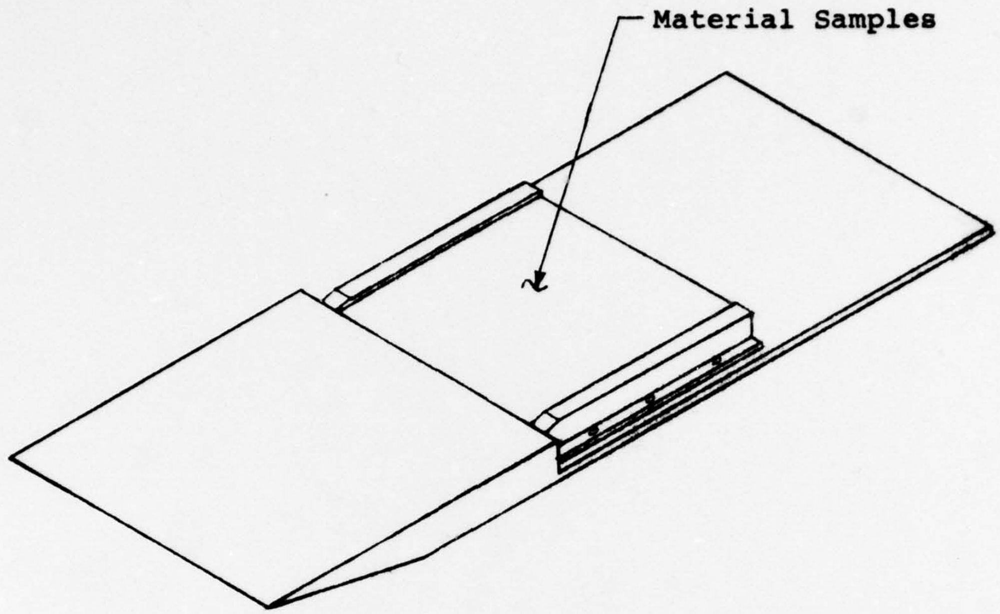
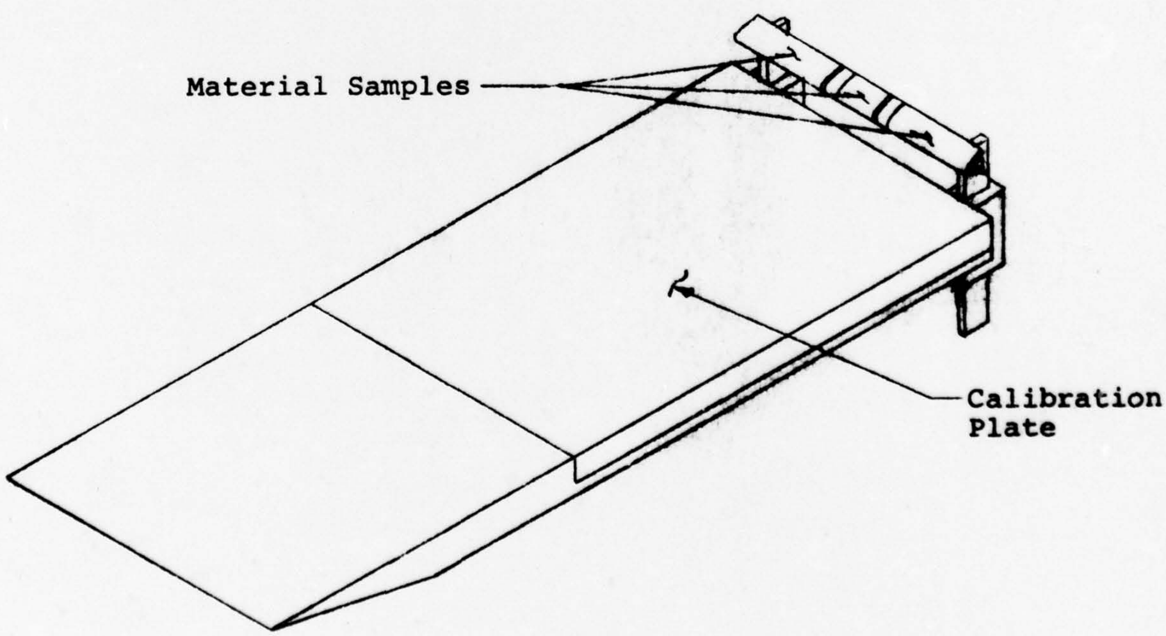


FIGURE 2. SKETCH OF MATERIALS WEDGE



a) Flat Panel Specimens



b) Leading Edge Specimens

FIGURE 3. SKETCH OF MATERIAL SUPPORT TECHNIQUES

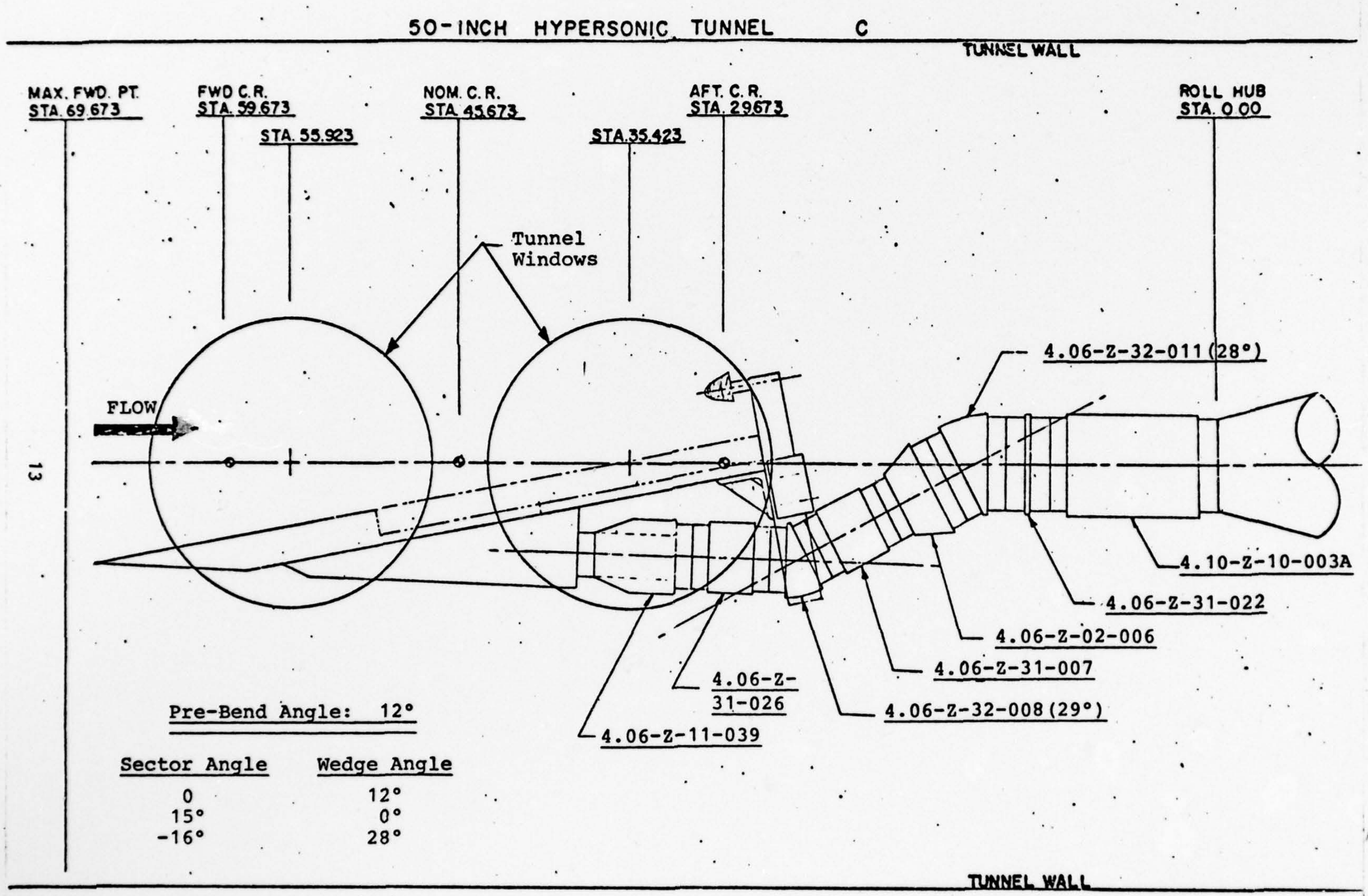
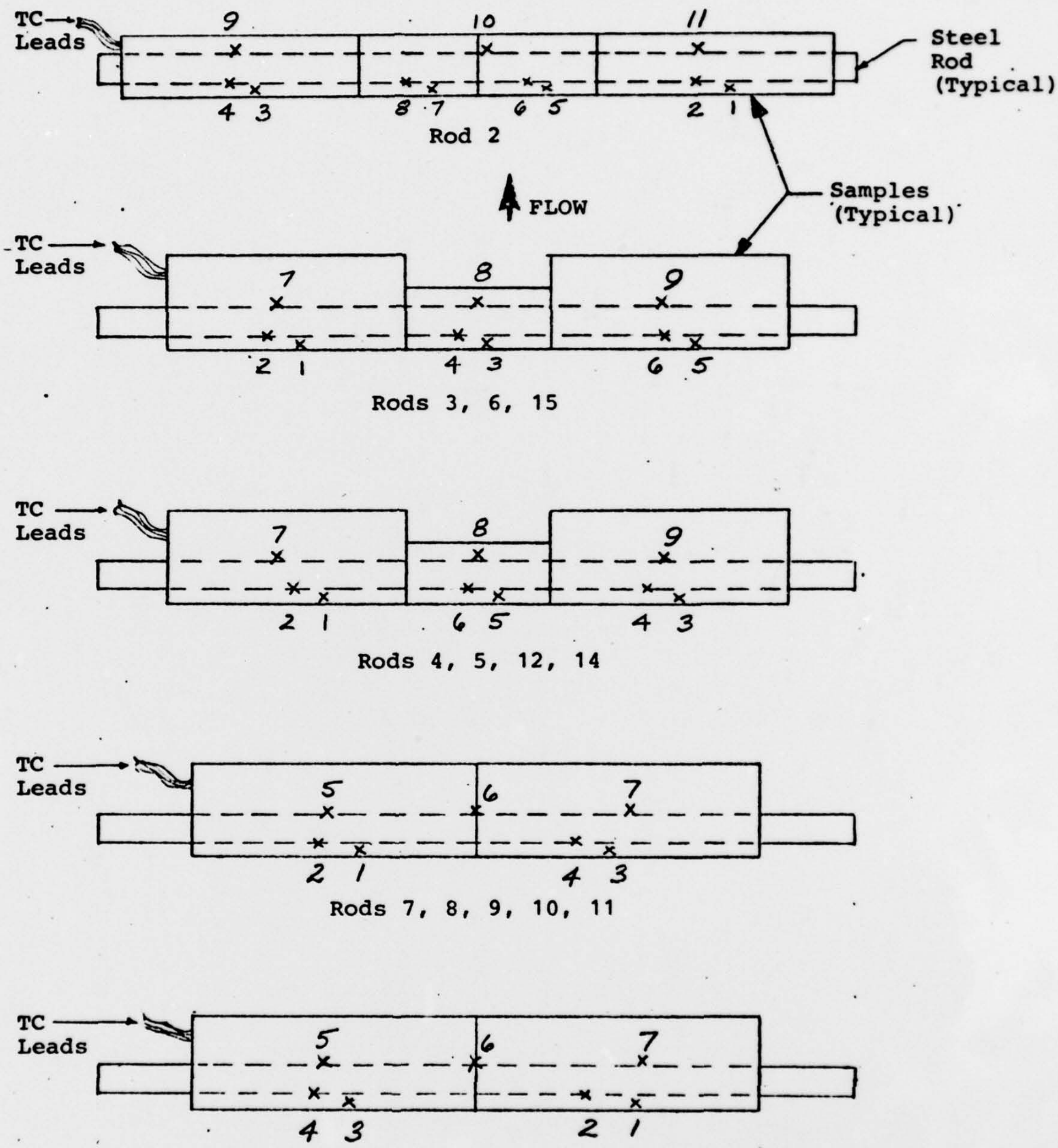


FIGURE 4. INSTALLATION SKETCH

For Front Face TC's - Even numbered TC's are located on backside of front surface. Odd number TC's are in a hole (0.045") from front surface.

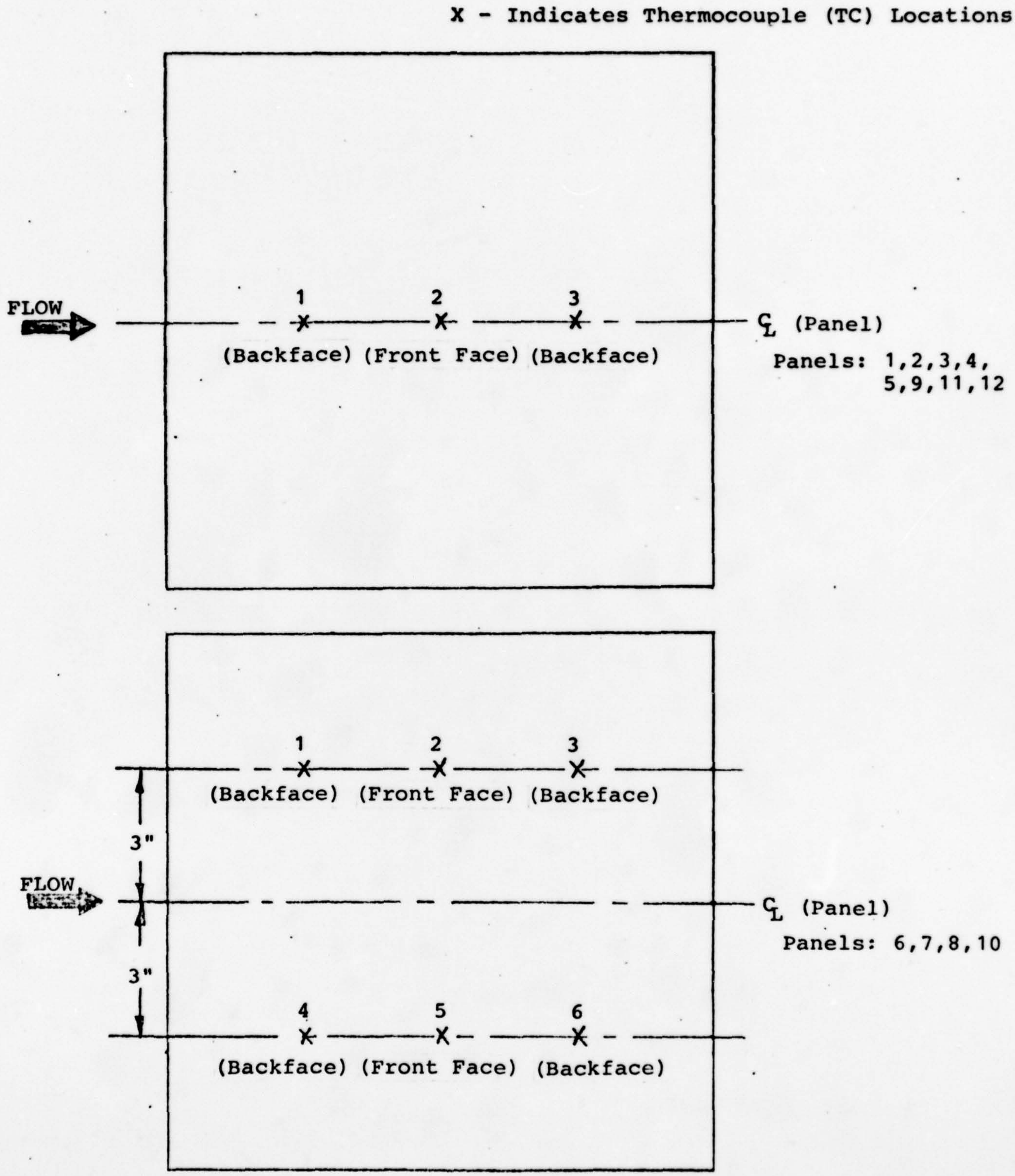


Rods 1, 13

X - Indicates Thermocouple (TC) Location

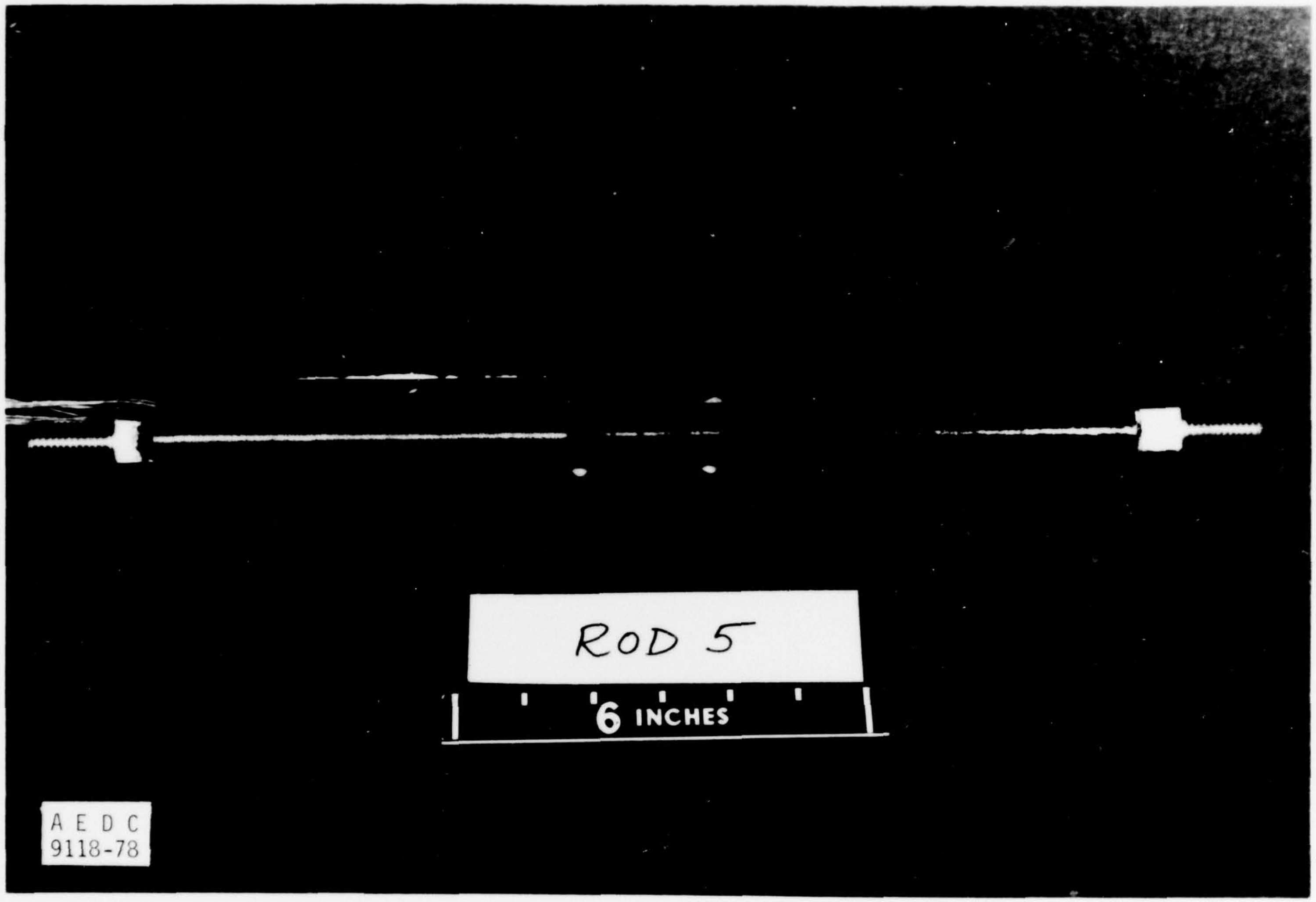
a) Top View Of Typical Leading Edge Specimens

FIGURE 5. MATERIAL SAMPLE THERMOCOUPLE LOCATIONS



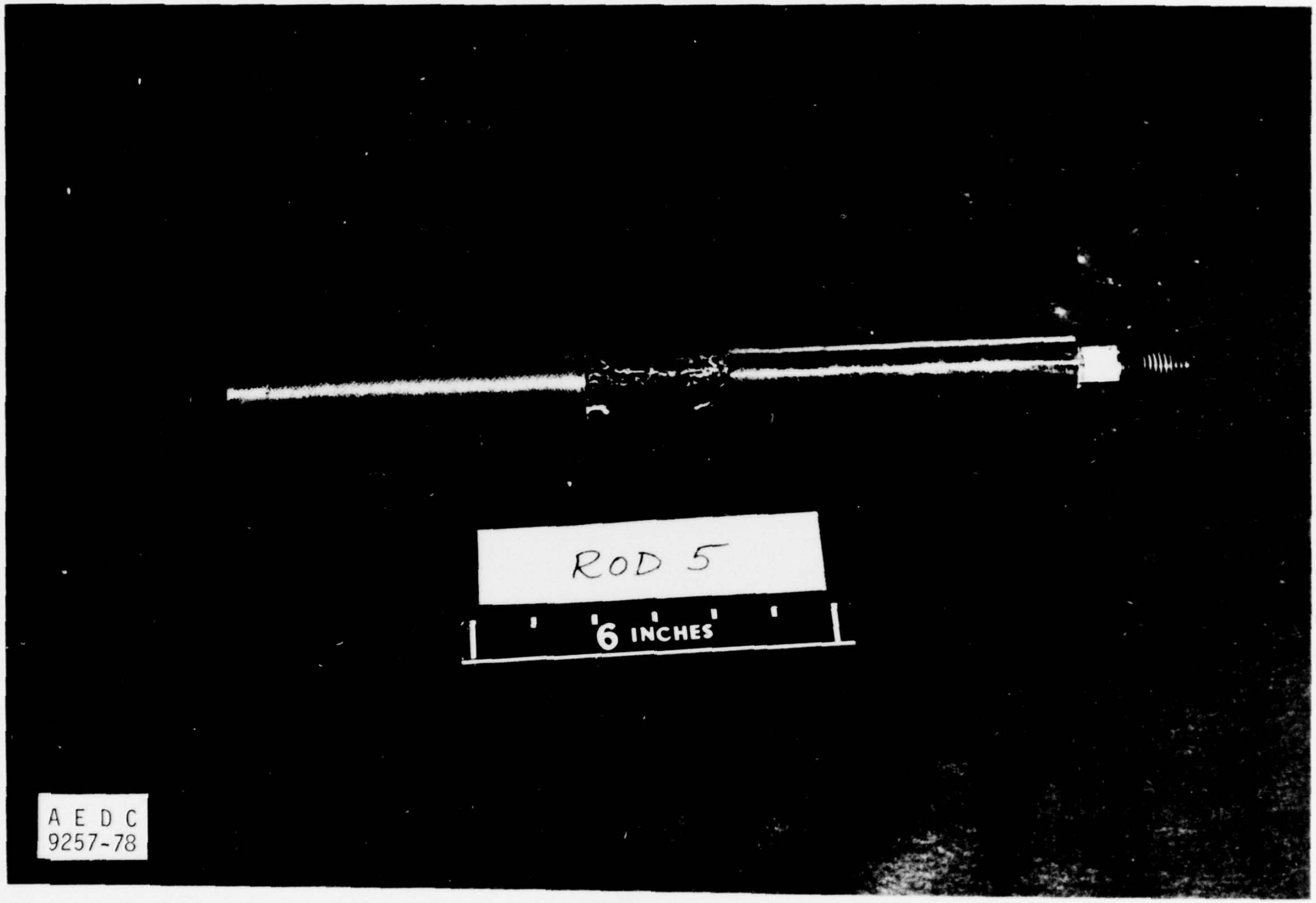
b) Top View Of Typical Flat Panel Specimens

FIGURE 5. CONCLUDED



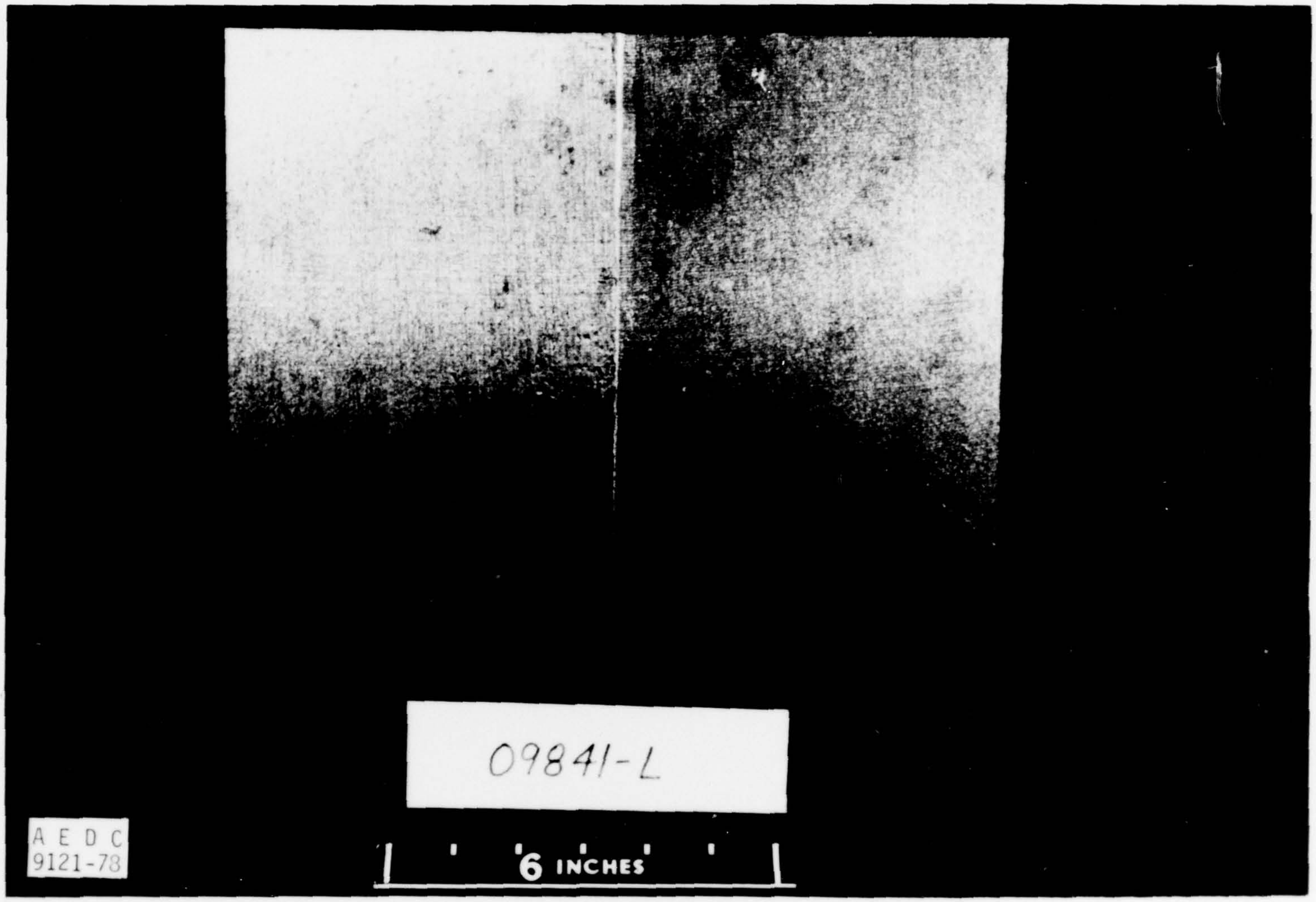
a) Pretest Photo

FIGURE 6. EXAMPLE PHOTO OF LEADING EDGE SPECIMEN (SAMPLE NUMBER 5, PMR-15/CELION 6000 WITH EROSION BARRIERS)



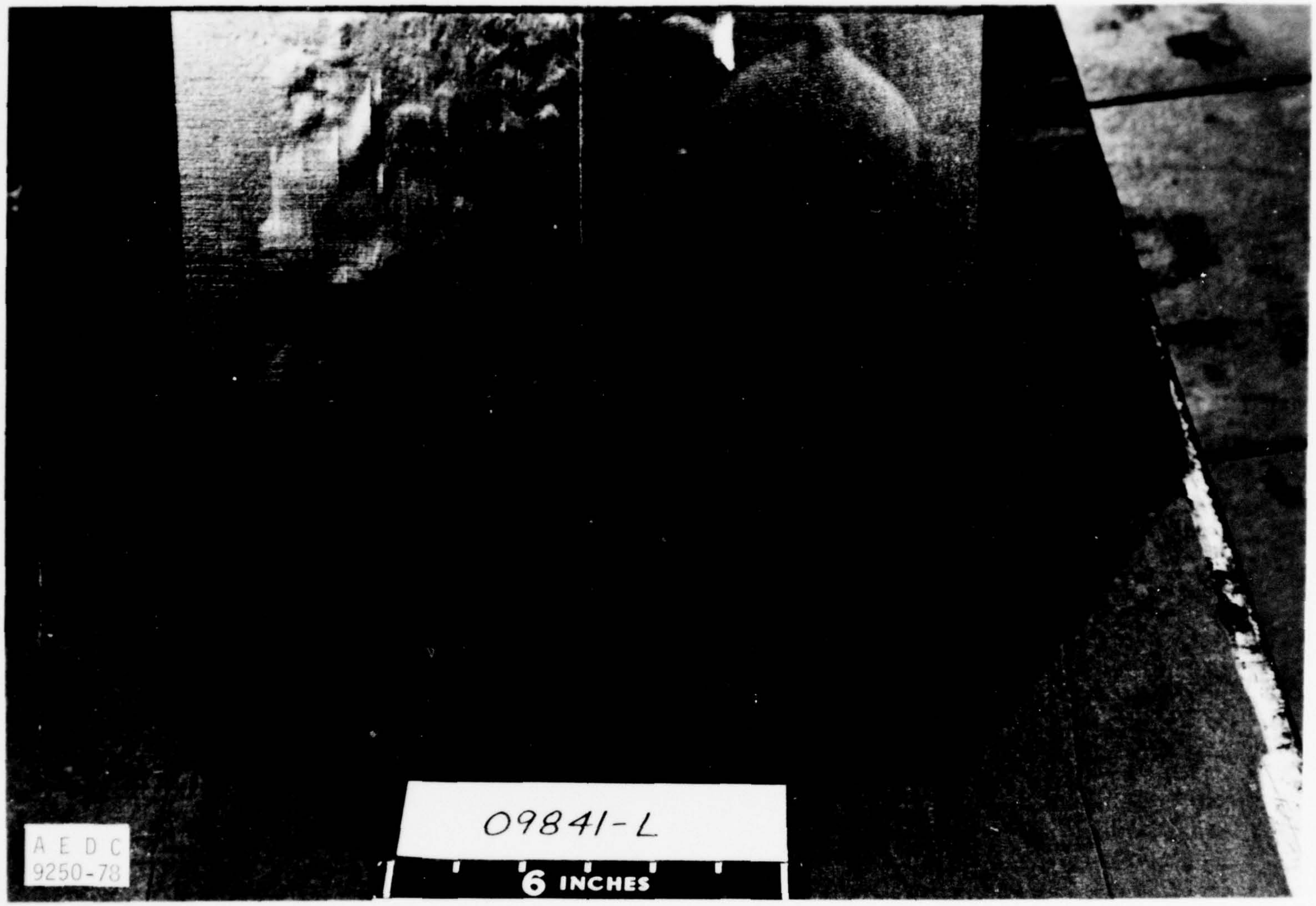
b) Posttest Photo

FIGURE 6. CONCLUDED



a) Pretest Photo

FIGURE 7. EXAMPLE PHOTO OF FLAT PANEL SPECIMEN (SAMPLE NUMBER 22, PMR-15/CELION 6000 1/2 COATED WITH S-GLASS)



b) Posttest Photo

FIGURE 7. CONCLUDED

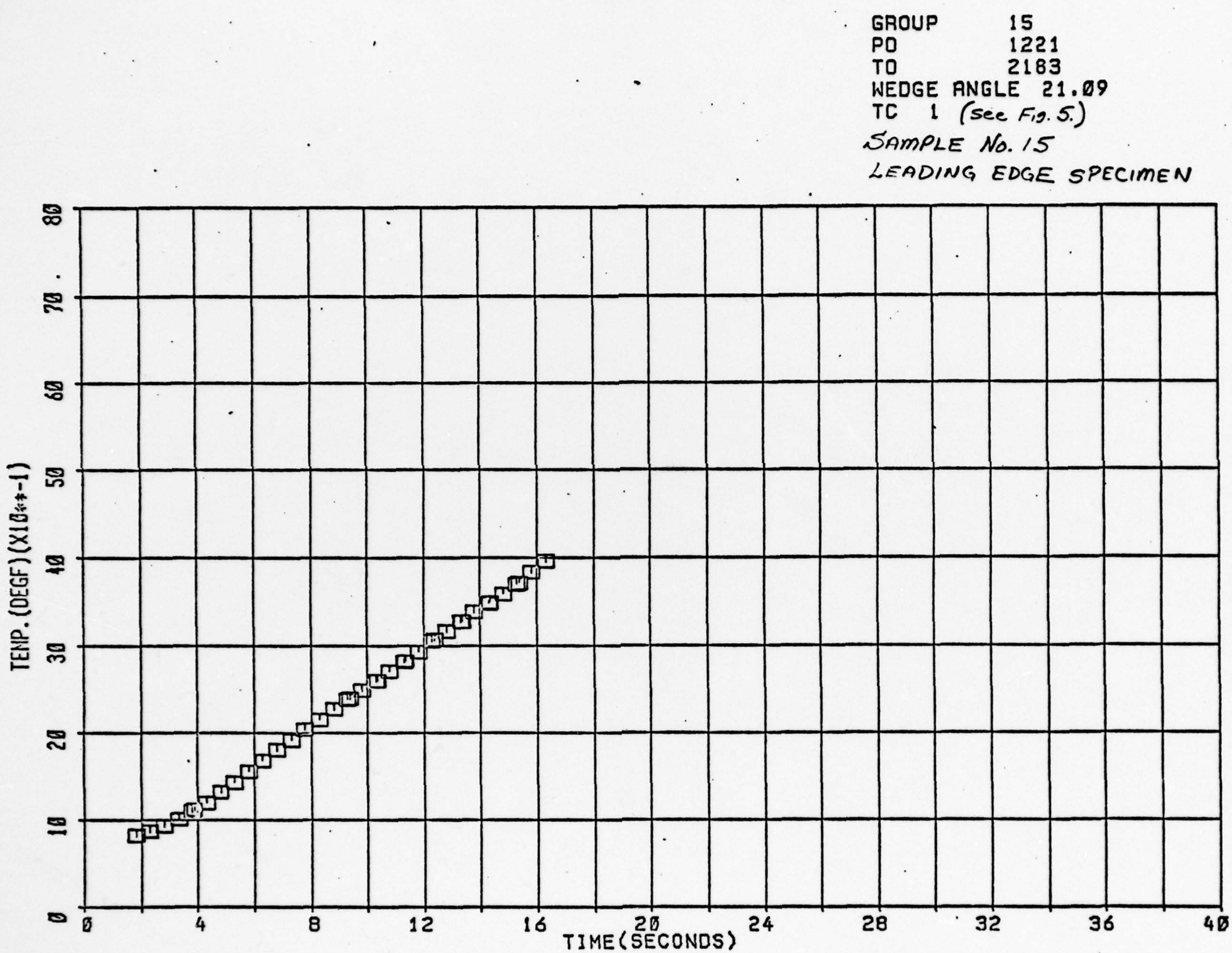


FIGURE 8. TYPICAL PLOT OF SPECIMEN FRONT FACE TEMPERATURE-TIME HISTORY (PMR-15/S-GLASS)

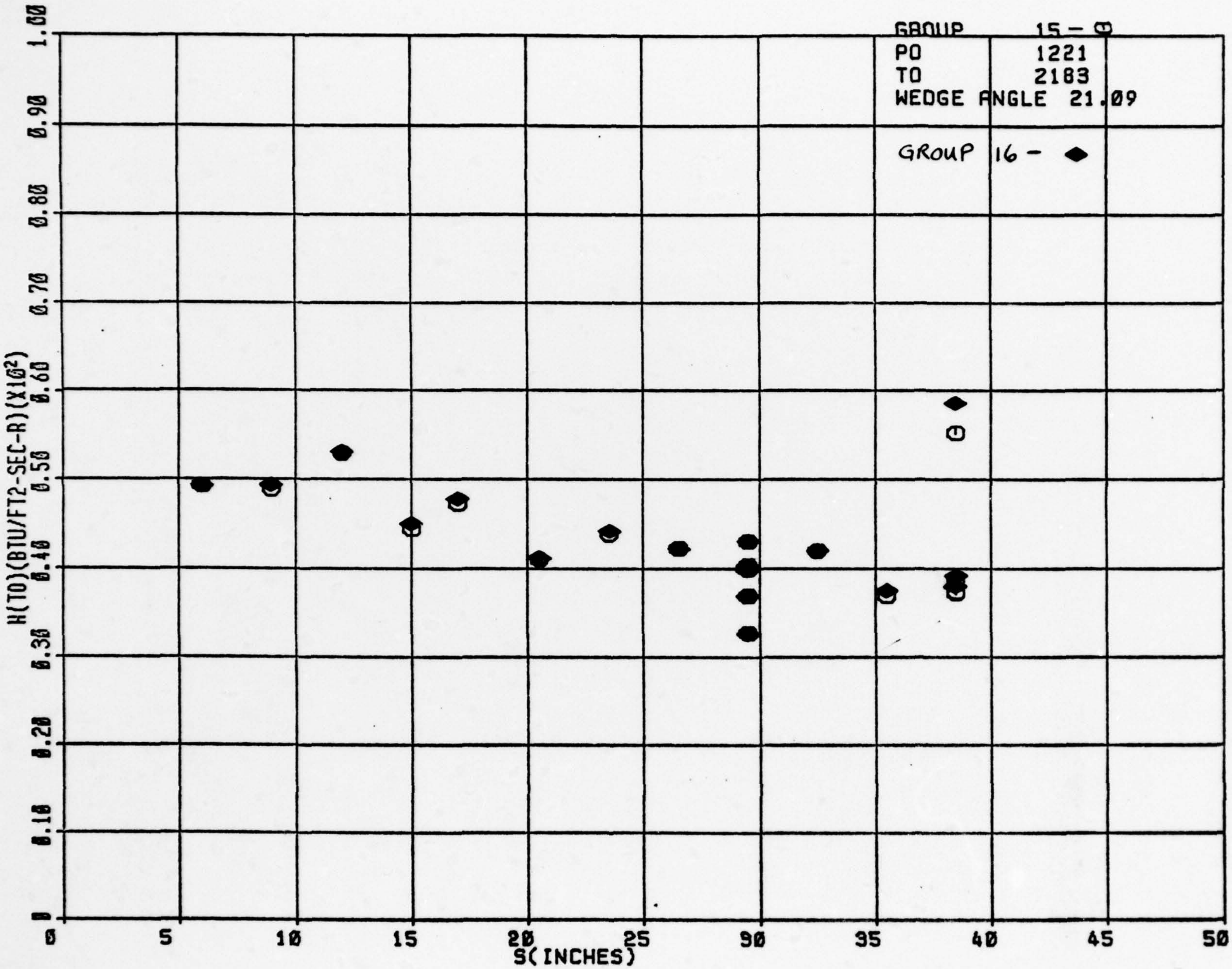


FIGURE 9. TYPICAL GARDON GAGE DATA PLOT

ARO, INC. - AEDC DIVISION
A SVERDRUP CORPORATION COMPANY
VON KARMAN GAS DYNAMICS FACILITY
ARNOLD AIR FORCE STATION, TENNESSEE
AFML MATERIALS SCREENING TEST

DATE COMPUTED 25-OCT-78
TIME COMPUTED 07:16:09
DATE RECORDED 12-OCT-78
TIME RECORDED 4: 4:12
PROJECT NUMBER V41C-W3

50 INCH HYPERSONIC TUNNEL C

PAGE 1

GROUP	CONFIG NUMBER	SAMPLE NUMBER	MACH NUMBER	PO (PSIA)	TO (DEG R)	ALPHA-SECTOR (DEG)	WEDGE ANGLE (DEG)	ROLL-SECTOR (DEG)	CENTERLINE (HOUR MIN SEC MSEC)
15	-1	15	10.14	1221.	2183.	-9.09	21.09	0.00	4 4 35 248

T-INF (DEG R)	P-INF (PSIA)	Q-INF (PSIA)	V-INF (FT/SEC)	RHO-INF (LB/FT3)	MU-INF (LB-SEC/FT2)	RE/FT (FT-1)	HO (BTU/LBM)	INJECT TIME (SEC)	EXPOSURE TIME (SEC)	C.R.
107.8	0.025	1.770	5162.	6.155E-04	8.679E-08	1.138E+06	5.570E+02	4.13	16.81	0.

WEDGE ATTITUDE AND TEMPERATURE HISTORY

TIME (SEC)	ALPHA SECTOR (DEG)	WEDGE ANGLE (DEG)	TC1 (DEG F)	TC2 (DEG F)	TC3 (DEG F)	TC4 (DEG F)	TC5 (DEG F)	TC6 (DEG F)	TC7 (DEG F)	TC8 (DEG F)	TC9 (DEG F)	TC10 (DEG F)	TC11 (DEG F)
1.8	-9.09	21.09	81.	77.	78.	78.	78.	79.	90.	88.	85.		
2.3	-9.09	21.09	87.	77.	79.	78.	78.	79.	92.	91.	85.		
2.8	-9.09	21.09	93.	78.	80.	79.	78.	79.	94.	95.	85.		
3.3	-9.09	21.09	101.	78.	82.	80.	78.	79.	97.	98.	85.		
3.8	-9.09	21.09	110.	80.	84.	83.	78.	79.	100.	101.	85.		
3.9	-9.09	21.09	111.	80.	85.	83.	78.	80.	100.	101.	85.		
4.3	-9.09	21.09	120.	81.	87.	85.	78.	79.	103.	104.	85.		
4.8	-9.09	21.09	132.	84.	91.	89.	80.	80.	106.	106.	85.		
5.3	-9.09	21.09	143.	87.	96.	93.	82.	81.	109.	110.	85.		
5.8	-9.09	21.09	156.	90.	101.	98.	83.	82.	112.	113.	85.		
6.3	-9.09	21.09	168.	93.	105.	104.	85.	82.	115.	115.	85.		
6.8	-9.09	21.09	180.	97.	110.	109.	86.	82.	118.	118.	85.		
7.3	-9.09	21.09	192.	101.	116.	115.	88.	82.	121.	120.	86.		
7.8	-9.09	21.09	204.	105.	123.	121.	90.	83.	125.	123.	87.		
8.3	-9.09	21.09	215.	110.	130.	129.	93.	83.	126.	126.	89.		
8.8	-9.09	21.09	227.	115.	138.	137.	97.	84.	131.	130.	92.		
9.3	-9.09	21.09	239.	121.	149.	146.	101.	87.	134.	134.	97.		
9.4	-9.09	21.09	240.	122.	150.	147.	101.	87.	135.	135.	98.		
9.8	-9.09	21.09	249.	127.	158.	155.	106.	90.	139.	139.	103.		
10.3	-9.09	21.09	260.	134.	166.	165.	113.	94.	145.	146.	106.		
10.4	-9.09	21.09	261.	135.	167.	166.	113.	94.	146.	147.	106.		
10.9	-9.09	21.09	272.	141.	176.	172.	121.	96.	155.	153.	108.		
11.3	-9.09	21.09	282.	150.	185.	181.	134.	100.	167.	161.	108.		
11.4	-9.09	21.09	283.	151.	186.	182.	135.	101.	168.	162.	107.		
11.8	-9.09	21.09	294.	160.	192.	190.	152.	106.	181.	168.	108.		
12.3	-9.09	21.09	305.	172.	198.	199.	175.	111.	194.	172.	109.		
12.4	-9.09	21.09	307.	173.	199.	200.	178.	112.	195.	172.	109.		
12.8	-9.09	21.09	316.	185.	210.	209.	200.	118.	205.	173.	111.		
13.3	-9.09	21.09	327.	204.	214.	218.	221.	125.	213.	175.	113.		
13.4	-9.09	21.09	328.	206.	215.	219.	224.	125.	214.	175.	113.		
13.8	-9.09	21.09	338.	223.	228.	226.	240.	129.	219.	175.	115.		

FIGURE 10. SAMPLE TABULATED DATA

ARO, INC. - AEDC DIVISION
A SVERDRUP CORPORATION COMPANY
VON KARMAN GAS DYNAMICS FACILITY
ARNOLD AIR FORCE STATION, TENNESSEE
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50 INCH HYPERSONIC TUNNEL C

GROUP	CONFIG NUMBER	SAMPLE NUMBER	MACH NUMBER	PO (PSIA)	TO (DEG R)	ALPHA-SECTOR (DEG)	WEDGE ANGLE (DEG)	ROLL-SECTOR (DEG)	CENTERLINE (HOUR MIN SEC MSEC)
15	1	15	10.14	1221.	2183.	-9.09	21.09	0.00	4 4 35 248

T-INF (DEG R)	P-INF (PSIA)	Q-INF (PSIA)	V-INF (FT/SEC)	RHO-INF (LB/FT3)	MU-INF (LB-SEC/FT2)	RE/FT (FT-1)	HO (BTU/LBM)	INJECT TIME (SEC)	EXPOSURE TIME (SEC)	C.R.
107.8	0.025	1.770	5162.	6.155E-04	8.679E-08	1.138E+06	5.570E+02	4.13	16.81	0.

WEDGE ATTITUDE AND TEMPERATURE HISTORY

TIME (SEC)	ALPHA SECTOR (DEG)	WEDGE ANGLE (DEG)	TC1 (DEG F)	TC2 (DEG F)	TC3 (DEG F)	TC4 (DEG F)	TC5 (DEG F)	TC6 (DEG F)	TC7 (DEG F)	TC8 (DEG F)	TC9 (DEG F)	TC10 (DEG F)	TC11 (DEG F)
14.3	-9.09	21.09	349.	245.	261.	235.	256.	132.	223.	175.	115.		
14.4	-9.09	21.09	350.	247.	263.	235.	258.	132.	223.	174.	115.		
14.8	-9.09	21.09	359.	259.	305.	242.	269.	137.	224.	174.	116.		
15.3	-9.09	21.09	371.	270.	228.	249.	279.	146.	222.	172.	118.		
15.4	-9.09	21.09	372.	271.	229.	250.	280.	147.	222.	173.	118.		
15.8	-9.09	21.09	384.	284.	232.	256.	286.	151.	219.	172.	119.		
16.3	-9.09	21.09	396.	302.	244.	262.	289.	156.	219.	174.	121.		

FIGURE 10. CONTINUED

ARO, INC. - AEDC DIVISION
A SVERDRUP CORPORATION COMPANY
VON KARMAN GAS DYNAMICS FACILITY
ARNOLD AIR FORCE STATION, TENNESSEE
AFML MATERIALS SCREENING TEST

DATE COMPUTED 25-OCT-78
TIME COMPUTED 07:16:10
DATE RECORDED 12-OCT-78
TIME RECORDED 4: 4:12
PROJECT NUMBER V41C-W3

50 INCH HYPERSONIC TUNNEL C

GROUP	CONFIG NUMBER	SAMPLE NUMBER	MACH NUMBER	PO (PSIA)	TO (DEG R)	ALPHA-SECTOR (DEG)	WEDGE ANGLE (DEG)	ROLL-SECTOR (DEG)	CENTERLINE (HOUR MIN SEC MSEC)
15	1	15	10.14	1221.	2183.	-9.09	21.09	0.00	4 4 35 248

T-INF (DEG R)	P-INF (PSIA)	Q-INF (PSIA)	V-INF (FT/SEC)	RHO-INF (LB/FT3)	MU-INF (LB-SEC/FT2)	RE/FT (FT-1)	HO (BTU/LBM)	INJECT TIME (SEC)	EXPOSURE TIME (SEC)	C.R.
107.8	0.025	1.770	5162.	6.155E-04	8.679E-08	1.138E+06	5.570E+02	4.13	16.81	0.

GARDON GAGE DATA

GAGE NO	X (IN)	Y (IN)	Z (IN)	S (IN)	TW (DEG R)	TGE (DEG R)	DELT (DEG R)	Q-DOT (BTU/FT2-SEC)	H(TO) (BTU/FT2-SEC-R)
1	6.0	0.0	0.0	6.0	649.01	618.22	41.05	7.57	4.937E-03
2	9.0	0.0	0.0	9.0	652.32	619.48	43.78	7.49	4.893E-03
3	12.0	0.0	0.0	12.0	640.32	616.36	31.94	8.18	5.303E-03
4	15.0	0.0	0.0	15.0	633.95	609.89	32.08	6.90	4.452E-03
5	17.0	0.0	0.0	17.0	643.20	613.36	39.78	7.28	4.726E-03
6	20.5	0.0	0.0	20.5	639.04	612.97	34.76	6.34	4.109E-03
7	23.5	0.0	0.0	23.5	644.14	615.23	38.54	6.76	4.394E-03
8	26.5	0.0	0.0	26.5	643.13	621.22	29.22	6.51	4.228E-03
9	29.5	0.0	0.0	29.5	653.45	628.50	33.26	6.59	4.307E-03
10	32.5	0.0	0.0	32.5	665.49	632.49	44.00	6.38	4.207E-03
11	35.5	0.0	0.0	35.5	663.86	642.28	28.78	5.62	3.700E-03
12	38.5	0.0	0.0	38.5	667.95	645.31	30.18	5.90	3.896E-03
13	29.5	0.0	-5.0	29.5	650.22	628.11	29.48	5.02	3.276E-03
14	29.5	0.0	-2.5	29.5	652.16	628.93	30.98	6.20	4.048E-03
15	29.5	0.0	2.5	29.5	643.90	619.22	32.91	6.15	3.999E-03
16	29.5	0.0	5.0	29.5	650.54	625.29	33.66	5.67	3.702E-03
17	38.5	0.0	-5.0	38.5	736.18	666.62	92.75	16.27	1.125E-02
18	38.5	0.0	-2.5	38.5	696.41	656.42	53.33	8.22	5.528E-03
19	38.5	0.0	2.5	38.5	671.00	647.31	31.59	5.65	3.739E-03
20	38.5	0.0	5.0	38.5	661.88	643.93	23.94	5.66	3.723E-03

FIGURE 10. CONCLUDED

APPENDIX II

TABLES

TABLE 1. LIST OF MATERIAL SPECIMENS

SAMPLE NUMBER	SAMPLE TYPE	SAMPLE CODE: MATERIAL ID NUMBER
1	LEADING EDGE	ROD 1: CH841-3A[1], DWA2[3]
2		ROD 2: TRW5A[1], H1[2], H2, TRW5B
3		ROD 3: CH857-07A, H6, TRW8
4		ROD 4: CH878-9C, H7, CH857-09A
5		ROD 5: CH841-3B, H8, CH878-10B
6		ROD 6: CH857-11C, H9, CH857-09B
7		ROD 7: CH8H-2A, DWA4
8		ROD 8: CH857-012, DWA5
9		ROD 9: CH878-10C, DWA1
10		ROD 10: CH878-10A, DWA3
11		ROD 11: CH841-2B, DWA6
12		ROD 12: CH857-07B, H3, TRW6A
13		ROD 13: CH841-3C, CH841-2C
14		ROD 14: CH857-11B, H4, TRW7A
15	LEADING EDGE	ROD 15: CH857-11A, H5, TRW7B
16	FLAT PANEL	PANEL 1: 09857-G[1]
17		PANEL 2: BORON/ALUMINUM-2[3]
18		PANEL 3: TRW773[1]
19		PANEL 4: 09857-I
20		PANEL 5: BORON/ALUMINUM-1
21		PANEL 6: 09878-A
22		PANEL 7: 09841-L
23		PANEL 8: 09878-B
24		PANEL 9: TRW773-84
25		PANEL 10: 09841-M
26		PANEL 11: 09878-E
27	FLAT PANEL	PANEL 12: HUGHES 2[2]

KEY: (1) CH NUMBERS, NUMERAL NUMBERS, AND TRW DESIGNATIONS REPRESENT PMR-15 TYPE POLYIMIDE COMPOSITES

(2) H NUMBERS REPRESENT THERMAL TYPE POLYIMIDES

(3) BORON/ALUMINUM AND DWA REPRESENTS A BORON/ALUMINUM TYPE OF METAL MATRIX COMPOSITE

TABLE 2. TEST SUMMARY

CONFIG. CODE	CONFIGURATION TYPE	SAMPLE NUMBER	WEDGE ANGLE (DEG)	EXPOSURE TIME (SEC)	DATA GROUP NUMBER
1	Leading Edge	8	21	13.8	1
		8	21	39.5	2
		3	21	12.8	3
		3	12	11.8	4
		2	21	11.8	5
		2		12.8	6
		9		21.3	7
		6		20.3	8
		14		21.3	9
		10		22.3	10
		4		22.3	11
		12		17.3	12
		1		17.8	13
		13		17.3	14
		15		16.8	15
		5		17.3	16
		11		8.3	17
1	Leading Edge	7	21	6.3	18
2	Flat Panel	16	21	22.8	19
		17		31.3	20
		18		32.8	21
		19		33.3	22
		20		29.3	23
		21		30.3	24
		22		33.8	25
		23		31.3	26
		24		29.8	27
		25		34.3	28
		26		28.3	29
2	Flat Panel	27	21	35.3	30